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I, JULIE BILLINGSLEY, TEAM LEADER EXAMINATION SUPPORT AND SALES hereby certify that annexed is a true copy of the Provisional specification in connection with Application No. PR 7832 for a patent by TELE-IP LIMITED as filed on 21 September 2001.



WITNESS my hand this
Eighteenth day of February 2004

A handwritten signature in cursive script, appearing to read "J. Billingsley".

**JULIE BILLINGSLEY
TEAM LEADER EXAMINATION
SUPPORT AND SALES**

ORIGINAL

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AUSTRALIA

Patents Act 1990

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PROVISIONAL PATENT SPECIFICATION

Patent Application No:

Application Date:

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INVENTION TITLE: Detection of Clear-Air Turbulence from Aircraft

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The invention is described in the following statement:—

TITLE: Detection of Clear-Air Turbulence from Aircraft

TECHNICAL FIELD

This invention relates to the use of acoustic pulses for the detection of clear-air
5 turbulence (CAT) from aircraft, to airborne warning systems capable of warning of
CAT and to associated techniques.

BACKGROUND TO THE INVENTION

There has long been a need for an airborne warning system capable of detecting
10 CAT from an aircraft in flight. When an aircraft runs into CAT, passengers and
crew can be thrown about and luggage dislodged causing injury. In extreme
cases, the aircraft can sustain structural damage and even crash. There are
frequent reports of planes suddenly dropping several thousand feet after CAT in
the form of a rotating air system or down-draft. Unfortunately, airborne radar is
15 unable to detect CAT, even when it is severe.

OUTLINE OF THE INVENTION

The present invention is based upon the realization that the forward projection of
acoustic chirps from an aircraft can be used to detect CAT, even when the aircraft
20 is traveling at up to 0.8 Mach, which is now the cruising speed of many modern jet
airliners. Though the acoustic pulses will be traveling forward at only 0.2 Mach
relative to the aircraft, the lower acoustic resistance and dissipation of air at
cruising altitude, the very high system gains using chirp techniques and the
benefits provided by the high Doppler shift caused by the speed of the aircraft are,
25 surprisingly, sufficient to provide a useful range and therefore, warning period.

From one aspect, therefore, the present invention comprises an acoustic
sounding system for use in aircraft for warning of CAT ahead of the craft, the
system comprising an electro-acoustic transmitter adapted to project a series of
30 acoustic chirps forward and ahead of the aircraft, an acousto-electric receiver
adapted to detect acoustic echoes of the transmitted chirps traveling toward the
aircraft, auto-correllator means for processing the echo signals adapted to detect
echo chirps and alarm means connected to the auto-correllator means for

generating an alarm signal when echoes having a signal energy or strength above a given threshold are detected.

For high-speed aircraft (up to about 0.8 Mach), it will usually be sufficient to
5 generate a near-continuous series of chirps, to discriminate over chirps that travel a direct path through the aircraft or are transmitted through the air surrounding the aircraft direct from the transmitter to the receiver and to sound the alarm as soon as echo chirps are detected. Such discrimination can be highly effective by using an electrical signal derived from the transmitter corresponding to the transmitted
10 chirps and/or by using the fact that echo chirps will have a high Doppler-shift while the 'direct' chirps will not. In this way very system high signal to noise [s/n] ratios can be obtained. This translates into high sensitivity and, thus, long range detection.

15 For lower speed aircraft (say 0.1 – 0.5 Mach), there can be sufficient time interval between successive chirps to permit comparison of transmitted and received chirps in a manner that allows the range of the reflecting CAT to be determined. Our prior patent applications PCT/AU01/00247 and PR7203 disclose how suitable chirps can be generated, how transmitted and received chirps can be compared
20 by Fourier techniques and how and such ranging can be achieved using computer methods.

For an airborne system, it is envisaged that the transmitting and receiving transducers can be mounted in the leading edge(s) of the wing or wings or in the
25 nose cone of the aircraft. In one arrangement, for example, a transmitter can be arranged on the leading edge of one wing and a receiver can be arranged on the leading edge of the other wing. This arrangement minimizes the amplitude of the direct signal. In another arrangement, a plurality of transmitters can be arranged in a row or array on one wing and a plurality of receivers arranged in a row or
30 array on the other wing, thereby greatly increasing the acoustic power that can be transmitted and/or the sensitivity of detection and, if desired, permitting phase-array or steered beam techniques to be employed.

It is preferred to employ solid-state piezoelectric transducers fitted with suitable couplers to improve the coupling of the acoustic energy from the transducer to rarified air. However, it might be noted that the coupling problem is greatly aided by the fact that the density of air from the leading edge of the wing of a high-speed aircraft in flight increases considerably and inversely with distance from the wing over a metre or more.

The systems and apparatus of the invention are not heavy or expensive since they require only small transducers and the computing power of a lap-top computer.

As indicated above, the invention comprises methods for detecting CAT from aircraft of the type outlined above, systems for doing so and apparatus for mounting within aircraft for the purpose.

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DESCRIPTION OF EXAMPLE

Having portrayed the nature of the present invention, a particular example will now be described. However, those skilled in the art will appreciate that many variations and modifications can be made to the chosen example without departing from the scope of the invention as outlined above.

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The chosen example is a system for fitting to a typical jet airliner having a cruise altitude of 10,000 m and a cruise speed of 220 m/s (800 km/hr). In the chosen example, a piezoelectric acoustic transmitter capable of delivering 120 dBa sound energy at 500 Hz is located on the tip or in the leading edge of one wing of a jet aircraft so that its beam is directed straight ahead and a piezoelectric acoustic receiver is arranged in the tip or leading edge of the other wing, or in the nose of the plane so as to detect sound received from directly ahead of the aircraft. Commercial receive transducers of this type can readily have a sensitivity of better than 40 dBa, giving a basic system gain of 80 dBa. This figure can be substantially increased by employing an array of transmitters and receivers along each wing. The transmitter and receiver transducers can be of known design and commercially available.

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The transmitter is driven by a conventional audio amplifier from a signal processing unit and the receivers are connected via respective amplifiers to the processing unit. The processing unit can be a small computer and the system
 5 may be constructed and operated as described in our aforementioned international patent application to generate the transmitted chirps and to digitally sample and employ FFT (fast Fourier transform) techniques to enhance the s/n ratio, eliminate the direct signal from the transmitter (conducted via the airframe or through the air in the immediate vicinity of the aircraft) and to detect echo chirps in
 10 the received signal.

Conveniently in the case of this example, the transmitted chirp is of 3 - 5 seconds duration and increases linearly with time in frequency from about 400 Hz to about 800 Hz. However, a wide choice of duration and frequency ranges and durations
 15 are available. Generally, it will be preferable to select lower frequencies and shorter durations for high-flying jet aircraft and higher frequencies and longer durations for slower planes that operate at lower cruising altitudes.

The general formula for determining Doppler shift in this situation is the following:
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$$F_o = \{(v+w-V_o)/(v+w-V_s)\}F_s$$

Where: F_o is the observed frequency, v is the speed of sound in the surrounding air (about 344 m/s), w is the speed of the wind in the direction of the aircraft
 25 (assumed to be zero), V_o is the speed of the aircraft (assumed to be 220 m/s), V_s is the speed at which the CAT interface is moving toward the aircraft (assumed to be zero) and F_s is the frequency of the sound emitted by the transmitter (assumed to be 500 Hz for convenience).

30 Thus, the Doppler shift of the signal generated by the transmitter is $\{344/(344-220)500\}$ or 1433 Hz, giving a Doppler shift of about 2.8 times. The received echo chirp will also be Doppler-shifted by the moving aircraft to about 4100 Hz, given by $\{344/(344-220)1433\}$; that is, by the same factor of 2.8. This means, first, that the physical size of the receiving transducer can be greatly reduced with respect

to that of a transducer designed to receive signals at 500 Hz and, second, problem of discriminating between the direct and echo chirps is greatly simplified so that the chirps can be transmitted without the need for 'listening' intervals there-between. A noise gain of about 50 dB and a processing gain of about 25 dB
5 can therefore be expected.

It will be convenient to sample and digitize the received signal at 96 K samples per second, as disclosed in our prior applications, to give a correlator gain of 103 dB for a three second chirp and proportionately higher for longer chirps. Thus the
10 total system gain can be expected to be nearly 260 dB. Indeed, as indicated, the correlator gain can be significantly improved by employing longer chirps.

Taking the average Doppler-shifted chirp frequency to be 1000 Hz, the attenuation of a 1000 Hz signal in air at an altitude of 10,000 m to be 0.62 dB/km,
15 the distance from the aircraft to a region of CAT to be 75,000 m, and the speed of sound in air to be 340 m/s, then the echo chirp will reach the aircraft after it has traveled about 55,000 m and when it has about 20,000 m to go before it hits the CAT. At the speed of the aircraft (220 m/s) this gives a warning 90 seconds in advance. The chirp has traveled 95,000 m (75,000 out and 20,000 back). The
20 path attenuation of the chirp will therefore be about 59 dB. Assuming a reflection loss of 100 db at the CAT interface, the total signal loss is 159 dB. Thus, the signal to noise ratio is about 100 db (260 – 159).

This generous s/n ratio permits the detection of CATs at distances of up to 100
25 km with warning times of up to two minutes or more. Of course, two or three seconds of this time may be used to effect the FFT processing of the echo chirps.

As previously indicated, the continuous transmission of chirps does not allow for range determination but offers earlier detection and longer warning periods.
30 Transmission of chirps having durations of between 3 and 5 seconds space at intervals of similar duration will allow ranging in the manner disclosed in our prior applications, albeit with the loss of about 10 to 15 seconds due to 'listening' and processing times.

While some examples of the application of the invention have been described that offer significant advantages, it will be appreciated that the methods of the present invention can be applied widely to acoustic sounding and that many alterations
5 and additions can be made without departing from the scope of the invention as outlined above.

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Tele-IP Limited
By its Attorney
Paul A Grant
20 September 2001